Principles of Systems Engineering and Related Concepts

Marcel Ray Duriez

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Structural Steel Design Concepts: An Overview

Structural steel design is a fundamental aspect of engineering that ensures safety, durability, and efficiency in building and infrastructure projects. A comprehensive understanding of key concepts in steel connections, member design, and material properties is essential for engineers to create robust and reliable structures. This essay explores important principles of structural steel design, focusing on bolt types, connection methods, failure modes, and design philosophies.

One of the critical components in steel connections is the **High Strength Friction Grip (HSFG) bolt**. Unlike ordinary bearing type bolts that transfer loads through direct bearing on bolt shanks, HSFG bolts rely on friction between connected surfaces to resist forces. This design method necessitates careful determination of the bolt's proof load — the maximum load the bolt can safely carry without permanent deformation — to ensure the connection's reliability. HSFG bolts are primarily used where high external forces are present, making them unsuitable for low-load applications.

When designing **splices in tension members**, it is crucial to avoid eccentricity, which occurs when the load path does not align with the member's centroid. Eccentricity can cause unwanted bending moments and stress concentrations, compromising the structural integrity. Thus, splice connections must be arranged to

maintain axial load transfer, preventing additional bending stresses.

Steel members often face multiple potential failure modes, including **yielding of the gross section, rupture of the net section, and block shear**. The design strength of a member is governed by the weakest of these modes. For instance, if yielding capacity is 420.53 kN, rupture is 510 kN, and block shear is 421.53 kN, the design strength must be taken as 420.53 kN, the lowest value, to ensure safety.

In welded connections, particularly **fillet welds**, the design strength is calculated based on the effective throat area of the weld. This area directly influences the weld's capacity to resist applied loads, emphasizing the importance of accurate weld sizing and quality control.

Lug angles are versatile connection elements used in various scenarios, not limited to cases where gusset plates have sufficient length. Their adaptability makes them valuable for transferring loads in complex connection details.

Gusset plate connections must consider the alignment of connected members' centers of gravity. If these do not coincide, eccentricity arises, causing bending

moments that must be accounted for in the design. Such moments increase stress in the connection, requiring additional reinforcement or design modification.

Understanding the mechanics of moments in connections is fundamental. The moment is calculated as the product of the applied force and its perpendicular distance from the point of rotation. For example, a 20 kN load applied at 0.7 meters from a weld induces a moment of 14 kNm, which influences the weld design and the connected members' behavior.

When calculating the **nominal capacity of bolts** in tension, several parameters are essential: the net tensile stress area, ultimate tensile stress of the bolts, yield stress of the bolts, and the yield stress of the connected plate. The shank area of the bolt, however, is generally less relevant for ordinary black bolts under tension.

The **limit state design philosophy** underpins modern structural design by considering two main parameters: ultimate strength and serviceability. Ultimate strength addresses the maximum load a structure can sustain before failure, while serviceability ensures the structure performs adequately under normal use without excessive deformation or vibration. Safety is achieved by limiting material stresses and applying appropriate factors of safety.

Material properties also play a vital role. Increasing the **carbon content in steel** enhances its strength, enabling the manufacture of high strength carbon steels that allow for more efficient and lighter structural members without compromising performance.

In connections involving **angle members and gusset plates**, the net area of the member differs depending on the type of connection. Bolted connections reduce the net area due to bolt holes, while welded connections typically retain the gross section area, affecting the member's design strength.

Finally, the technique of **diamond bolting** involves increasing the number of bolts towards the center of the connection. This arrangement helps better resist eccentric loading by distributing forces more evenly and reducing the potential for bolt shear or bearing failure at the edges.

In summary, structural steel design is a complex field that requires a thorough understanding of materials, connection methods, failure mechanisms, and design principles. Mastery of these concepts enables engineers to create safe, efficient, and durable steel structures that meet the demands of modern construction.

In the realm of structural engineering, the integrity and efficiency of connections are paramount to the overall safety and performance of a structure. Through a series of insightful inquiries, we have delved into the foundational principles governing various aspects of steel connections, particularly focusing on eccentric loads, bolt and weld behaviors, and the crucial role of design codes. These discussions, akin to the distilled wisdom from a seasoned mentor, can be encapsulated as “The Teachings of Marcel Ray Duriez” on the practicalities of structural design.

One significant area of focus has been the design of eccentric connections, where loads are applied perpendicular to the plane of the joint, introducing both direct shear and bending effects. For welded joints, a systematic approach is essential. The process begins with the selection of a suitable weld size, from which the effective thickness and weld strength are computed. Subsequently, the direct shear stress and the stress due to bending are calculated, each needing to be less than the weld’s strength. A critical step involves calculating the weld’s necessary depth and potentially increasing it to adequately accommodate shear stress. Finally, an equivalent stress is determined, which must remain below the design weld strength. Should this condition not be met, the design necessitates an increase in weld length and a subsequent redesign, highlighting the iterative nature of engineering.

Similarly, in bolted joints subjected to eccentric loads perpendicular to their plane, the interaction between combined shear and tension is a critical design consideration. The interaction formula dictates that the square of the ratio of applied shear force to design shear capacity, added to the square of the ratio of applied tensile force to design tensile capacity, must be less than or equal to 1.0. This formula ensures the bolt's capacity to safely resist complex loading scenarios. Understanding the failure modes of bolts is equally vital. The primary modes include bearing failure of the plate (crushing of the plate material around the hole), shearing failure of the bolt (fracture of the bolt itself), and shear failure of the plate (often manifesting as block shear). While less commonly the primary failure mode, bearing failure of the bolt (deformation of the bolt material at the contact surface) is also a potential consideration. When calculating the nominal tensile capacity of an ordinary black bolt, key parameters include the net tensile stress area, the ultimate tensile stress of the bolts, the shank area of the bolt, and the yield stress of the bolt. This contrasts with High Strength Friction Grip (HSFG) bolts, whose design fundamentally differs from bearing-type bolts by relying on friction generated by high clamping forces, rather than direct bearing and shear.

The intricacies of welding were further explored, particularly the distinction between different weld types.

It was clarified that plug welds and slot welds are distinct from fillet welds. While fillet welds are typically triangular and join surfaces at right angles, plug and slot welds involve filling holes or elongated slots to connect overlapping plates. Crucially, the design strength of a fillet weld is always calculated based on its throat area, which is the shortest distance from the root of the weld to its face.

In the context of connecting angle sections to gusset plates, efficiency is a key design objective. It was established that connecting the longer leg via welding provides a more efficient connection. The increased connection length offered by the longer leg, combined with the continuous and rigid nature of welding, helps to minimize shear lag effects and distribute stresses more uniformly across the angle section.

Finally, a fundamental principle in structural design, applicable to any section, is the determination of its design strength. This is not simply the highest capacity, but rather the lowest value among all calculated limit state strengths, such as the design strength due to yielding of the gross section, rupture of the net section, and block shear. The structure will fail at the weakest link, thus the minimum value dictates its overall capacity. All these design considerations are guided by established standards, with IS 800–2007 being the correct Indian

code of practice for general steel construction that follows the Limit State Design method.

In essence, these “teachings” underscore the meticulous and multi-faceted nature of structural design. From selecting appropriate connection types and understanding their failure mechanisms to applying specific code provisions and iterative design processes, each step is critical to ensuring the safety, durability, and efficiency of steel structures.

Of Bolts and Brotherhood: An Ode to the Unsung Heroes of Structure

We, in our grand constructions, often speak of soaring heights and majestic spans. We celebrate the arch, the beam, the very bones of our edifices. But let us not forget the humble bolt, that steadfast servant of connection, without whom our dreams would crumble into dust.

To design a bolt group, is to orchestrate a silent ballet of forces. It is a process, a ritual, almost. We begin with a supposition, a whisper of diameter, as if consulting the oracle of strength. We seek the bolt value, that sacred measure of a single bolt’s worth in shear and bearing, a testament to its resilience.

Then, we ponder the multitude. How many of these metal warriors do we need? We calculate, we estimate, guided by the load, yet knowing that in the eccentric dance of forces, more will be asked of some than others. We arrange them, not as a haphazard mob, but as a disciplined company, each sharing the burden, yet some bearing more than their brothers.

For in the realm of eccentric loads, we find a subtle treachery. The load, like a wayward king, does not sit upon the throne of the group's center. It leans, it deviates, and thus, some bolts are crowned as critical, their burden magnified by the turning force, the moment.

We must then, with slide-rule and calculation, determine the resultant force, that vector sum of direct load and the twisting moment's decree. And in this, we seek assurance. Does the critical bolt, that hero of the group, bear a load that is less than its ordained value? If not, we must add to their number, or adjust their placement, until harmony is achieved.

And in the matter of a bolt's tensile capacity, we delve into the very sinew of the metal. We seek its ultimate tensile stress, that breaking point, the measure of its final defiance. We consider the net tensile stress area, for it is in the threaded waist that the bolt is most vulnerable. We

acknowledge the yield stress, and the shank area, for even in tension, the bolt has limits to its surrender.

The plate's yield, that is another tale, a story of the connected, not the connector.

So, let us honor the bolt, in its many forms. Let us design with care, with precision, and with a deep understanding of the forces at play. For in these small, unyielding servants, lies the strength of our grandest designs.

To: Professor Marcel Ray Duriez From: [Your Name/Student ID] Date: May 23, 2025 Subject: Comprehensive Review of Steel Structures: Design Principles and Practical Applications

Professor Duriez,

It is with considerable thought and reflection that I present this essay, aiming to synthesize the fundamental principles and practical applications of steel structures as we have diligently explored them throughout this course. Our discussions, particularly those delving into the nuances of design methodologies and the intricate behavior of steel elements, have significantly deepened my understanding of this fascinating field.

At the heart of steel structure design lies the overarching objective of safety and serviceability. This is robustly addressed by the Limit State Design philosophy, a modern approach that considers two paramount parameters: the Ultimate Limit State (ULS) and the Serviceability Limit State (SLS). ULS ensures the structure's integrity against collapse under extreme loads, encompassing checks for strength, stability, buckling, and fracture. Conversely, SLS guarantees the structure's performance and usability under normal service conditions, addressing critical aspects such as excessive deflection, vibration, and durability. This dual consideration stands in stark contrast to the **Working Stress Method**, which focuses solely on limiting stresses within the elastic range, and the **Ultimate Strength Method**, which, while considering ultimate strength, often employs a single factor of safety rather than distinct limit states. The preference for Limit State Design stems from its more realistic assessment of structural behavior and its ability to incorporate partial safety factors for both loads and material strengths, leading to more economical and reliable designs.

The very essence of a steel structure is defined by its constituent members, each meticulously designed to fulfill specific roles. Beams, typically horizontal elements, are primarily engineered to resist bending moments and shear forces. A critical distinction arises in their design:

whether they are **laterally supported** or **laterally unsupported**. A laterally supported beam, adequately braced along its compression flange, can achieve its full **plastic moment capacity**, as lateral-torsional buckling is prevented. In stark contrast, a laterally unsupported beam, lacking such restraint, is susceptible to this buckling phenomenon, which can significantly **reduce its design bending strength** to values considerably lower than its plastic capacity. Furthermore, the interaction of high shear forces with bending also necessitates a reduction in bending strength, emphasizing that these two internal forces are not entirely independent in their influence on a beam's ultimate capacity.

Columns, the vertical load-bearing elements, are designed predominantly for axial compression, but their strength is profoundly influenced by several factors. The **length of the member** and its **support conditions** are paramount, directly dictating its **effective length** and susceptibility to **buckling**. The **cross-sectional configuration** — be it an I-section, HSS, or angle — determines its area and moment of inertia, vital for resisting buckling. The **material properties** of the steel, specifically its yield strength and elastic modulus, define the material's inherent resistance. Finally, **residual stresses**, locked in during fabrication, can lead to premature yielding and a reduction in the

overall buckling strength. When considering built-up columns, lacing systems or batten plates are employed to ensure the individual components act as a unified member. Lacing bars must be appropriately inclined (typically between 40 and 70 degrees to the axis of the member) and are designed to resist a transverse shear force, commonly taken as 2.5% of the axial force in the main member. Batten plates, placed **perpendicular to the axis of the column**, serve a similar purpose of providing intermediate rigidity. The design of these systems must meticulously account for various **failure modes**, including the overall buckling of the built-up member, local buckling of individual components between lacing points, failure of the lacing members themselves, and distortion of the overall section.

Tension members, unlike their compressive counterparts, are designed to resist axial pulling forces. Their strength is fundamentally affected by the **gross area** and, crucially, the **net area** (reduced by **bolt holes**). Phenomena like shear lag (or axial lag, as sometimes referred to) can further reduce the effective area at connections, thereby lowering the member's tensile capacity. The spacing of fasteners and the ductility of the material also play vital roles; ductility allows for stress redistribution around stress concentrations, contributing to a more robust failure mode. When designing splices for tension members, the ideal is to ensure

that **eccentricity does not occur**, as any induced bending moment would significantly reduce the member's pure tensile capacity and complicate the design.

Connections, whether bolted or welded, are the linchpin of any steel structure. They are the means by which forces are transferred between members, and their design is as critical as that of the members themselves. For bolted connections, the choice between ordinary black bolts and **High Strength Friction Grip (HSFG) bolts** is crucial. HSFG bolts rely on friction generated by high pre-tensioning (related to the proof load) for load transfer, making them ideal for situations with high external forces or where slip must be prevented. The arrangement of bolts, such as **zig-zag bolting**, is often preferred over chain bolting due to its **efficiency** in providing a larger net area, thereby increasing the connection's tensile strength. Welded connections, such as butt welds and fillet welds, also have specific design considerations. The **effective length of a butt weld** should not be less than four times the size of the weld, and for fillet welds, the **effective throat thickness** (e.g., 0.7 times the weld size for a 90-degree angle) is paramount in determining its strength. Eccentrically loaded weld joints, where the load and the center of gravity of the weld are in **different positions**, introduce both **direct shear stress** and **torsional**

shear stress, both of which must be meticulously accounted for in design.

The design process itself for any steel member is iterative. For compression members, it typically involves determining effective length, assuming a design compression stress, calculating the required effective area, selecting a trial section, and then iteratively checking its slenderness ratio and load-carrying capacity against the design load. If the design capacity is significantly greater than the external load, the section must be **modified to be more economical**, preventing over-design and material waste.

Finally, specific structural elements like **purlins** and **gantry girders** present their own unique design challenges. Purlins, commonly channel or angle sections, are placed on rafters to support roof sheeting and are designed for bending moments. Gantry girders, critical for supporting overhead traveling cranes, must be designed to withstand a complex combination of loads: **vertical loads from cranes** (including impact factors), **longitudinal horizontal forces** due to crane acceleration/braking, and **lateral thrust** from crab movements.

In conclusion, Professor Duriez, the design of steel structures is a holistic and iterative process that demands

a thorough understanding of material behavior, structural mechanics, and codal provisions. From the fundamental principles of limit state design to the intricate details of connections and member behavior, each aspect contributes to the safety, serviceability, and economy of the final structure. The ability to integrate these diverse concepts and apply them practically, often aided by sophisticated software that allows for the input of critical parameters like ultimate tensile strength of bolts and analysis of various failure modes, is what defines a competent structural engineer. I am deeply appreciative of the insights gained through your guidance in navigating this complex but rewarding field.

Date: May 9, 2025 **Location Context:** Northern Cambria, Pennsylvania, United States

This document summarizes key concepts and definitions discussed in our recent interaction regarding systems engineering, reliability, project management, and related topics.

1. Error Recovery

There are two primary types of Error Recovery: **Backward Recovery** and **Forward Recovery**.

2. Hardware Redundancy

- **Passive Hardware Redundancy** utilizes masking to conceal faults and does not typically identify, declare, or report the source of the error.

- **Active Hardware Redundancy** involves techniques for error detection, location, and reporting. Common methods include:

- Pair and a Spare

- Hot standby sparing

- Recover from errors

- In **Cold Standby**, spare components are not in an active mode and are powered off until needed.

- **Active Redundancy** is generally the costliest type of redundancy to implement due to the operational overhead and complexity.

3. Social Dimensions in System Engineering (Sequence)

The social dimensions in system engineering can be viewed in a hierarchical sequence:

1. Individuals
2. Working groups/Team
3. Organizational Units
4. Single Organizations
5. Extended Multi-Organization Enterprises
6. Society, Nations, Communities, etc.

4. System Lifecycle Phases (Examples)

Examples of phases in the system lifecycle include:

- Implementation
- Full Scale Design
- Integration and Test

5. Space Shuttle Columbia Disaster

The Space Shuttle Columbia disintegrated on **February 1, 2003**.

6. Stage-Gate Process

In a stage-gate process, **every product stage will pass through a gate** for review and decision-making.

7. Objective Hierarchy

The objective hierarchy in system engineering typically has **2 to 5 levels**.

8. Technical Dimensions in Engineering

There is no universally fixed number of levels for Technical Dimensions in engineering. The categorization can vary depending on the system, framework, and context. While some models might use six levels for specific purposes, it is not a standard across all of engineering.

9. SM-65 Atlas Missile

The missile designed by the Air Force Ballistic Missile Division and built by the Convair Division of General Dynamics was the **SM-65 Atlas**.

10. Components of a Problem

A problem generally consists of three components:

- An undesirable initial state
- A desirable goal state
- Obstacles that prevent the transformation from the initial to the goal state

11. System Failure

A deviation in behavior between the system and its requirement is known as a **Failure**.

12. Judging and Perceiving Characteristics

- **Judging characteristics:**

- Focus on task-related action; complete meaning segments before moving on.

- Plan many of the details in advance before moving into action.

- **Perceiving characteristics:**

- Comfortable moving into action without a plan; plan on-the-go.

- Like to multitask, have variety, mix work and 1 play.

- 1. Should I Bring my Authentic Self to Work? — ppt download — SlidePlayer

- slideplayer.com

13. Functions of the Design Process (Sequence)

The typical sequence of the six functions in the design process is:

1. Define system level design problem

2. Develop the system operational architecture

3. Develop the system functional architecture

4. Develop the interface architecture

5. Develop the system physical architecture

6. Define the qualification system for the system

14. Mission Mode

Mission mode is the distinct operating capability of the system.

15. Overlap (Technical Definition)

An overlap is **a redundancy in functionality that is needed to achieve additional performance.**

16. United Airlines Flight 232 Crash

The United Airlines Flight 232 crash occurred in the year **1989**.

17. Personality Type and Energy Source

An **Extrovert** personality type gets its energy from outside.

18. Operational Concept

An **operational** concept is a vision for what the system is. It is a description of how the system will be used.

19. Identifying System Functions

We can identify the functions required in a system by using **IDEF0**, and the originating requirements documents.

20. System Types and Definitions

- **Natural System:** Systems that are existing in nature.
- **Artificial System:** Systems that are man made.

21. Functional Model Review (Key Actions)

When conducting a functional model review, it is important to:

- Try alternative decomposition
- Catch interface errors
- Disaggregate the functions differently

22. Major Processes for Product or System Development

Three major processes used for product or system development are:

- System vee
- Stage gate or waterfall process
- Spiral process

23. Hierarchical Function Structure

The Hierarchical function structure for a system involves decomposing functions into smaller functions and

showing them in a hierarchical way. This statement is **TRUE**.

24. Detecting Errors in a System (Examples)

Three common ways to detect errors in a system include:

- Spell checks
- Type checks
- Range checks

25. Method Composition in Functional Architecture

In functional architecture, ‘Method Composition’ is also known as the **Bottom up Approach**.

26. System Originating Requirements (Example)

The statement “The system shall prompt for identification and provide an opportunity to prove the

identity” is an example of a System Originating Requirement (**TRUE**).

This updated document compiles the key information from our conversation. Let me know if you’d like any specific section elaborated further!

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Architecture